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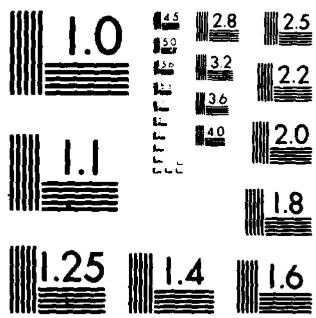

MICROCOPY RESOLUTION TEST CHART
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NAVSEA Propulsion Research Program

Program Element 61153N

Energy Contributions Associated with Combustion Instability

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Annual Progress Report

1 October 1980 - 30 September 1981

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Background

Combustion instability is a phenomenon which occurs in a wide variety of thermal energy systems including solid propellant rocket motors. The effects of combustion instability, such as propellant burning rate deviations, excessive heat transfer to motor components, perturbations in motor thrust, and mechanical vibration of the motor case and attached components, are well known and have caused a variety of problems both in the development and the operation of a number of rocket propulsion systems. The instability phenomenon is persistent and requires continued attention from both the research and the development communities.

The persistence of unstable combustion behavior in solid propellant rocket motors requires a level of expertise to be maintained in the field to provide for a rapid response to specific instability problems which periodically arise in Navy rocket propulsion systems. The tendency toward more sophisticated missile guidance and control systems and toward more elaborate warheads results in a higher degree of potential for missile or mission failure due to the effects of unstable combustion. The high cost of modern missile development and the increasingly stringent allowances for unstable combustion behavior require continued advancement in understanding of instability and further development of methods for predicting and controlling unstable combustion in solid propellant rocket motors.

Understanding of the sources of acoustic energy which give rise to combustion instability has increased considerably in the past decade. However, much remains to be accomplished to improve and extend the existing level of combustion instability technology. There are two areas of study which are thought to be capable of yielding useful results in the immediate future. One involves improvements in experimental measurement of the acoustic combustion response of solid propellants. A second area deals with the expansion of combustion stability analysis to include methods for quantitatively describing various acoustic phenomena which are known to occur in rocket motors but which are not adequately incorporated into existing motor stability assessment procedures at the present time.

Objectives

(1) To provide improved methods for experimentally determining the acoustic combustion response of solid propellants.

(2) To expand and add to existing combustion stability analysis to provide methods for describing non-linear phenomena and the effects of traveling acoustic waves in rocket motors.

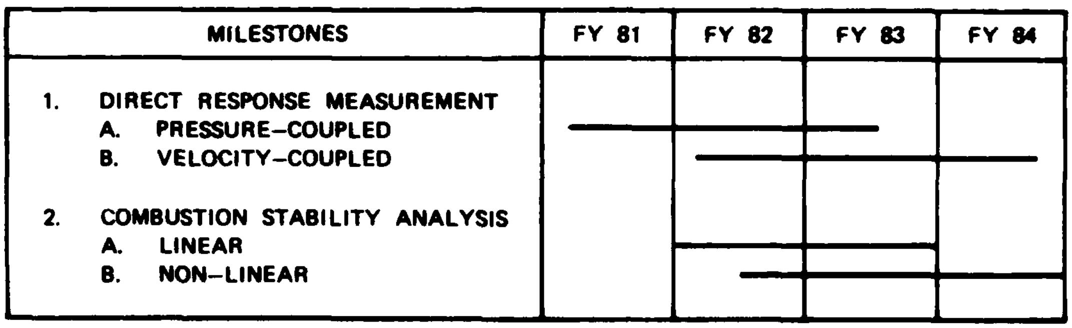
Approach

The investigation of new and novel laboratory test techniques for determining the acoustic energy contributions of burning propellants will be pursued. Emphasis will be on methods that provide a more direct measurement than presently

employed. Initial effort will be focused on methods for directly determining the response of solid propellant combustion to incident acoustic pressure waves. If successful, the method, or methods, for pressure-coupled measurement will be modified to provide direct velocity-coupled response meausrements. These methods are expected to lower the cost of characterizing the acoustic combustion response of solid propellant formulations of interest to the Navy and to provide improved accuracy of measurement.

The analytical description of acoustic energy contributions associated with combustion instability will be expanded to provide improvements to both linear and non-linear aspects of acoustic wave phenomena. Typical examples of phenomena requiring attention are: effect of traveling acoustic waves on motor stability, analytical description of mechanisms which impose finite limits on acoustic waves in motors, and description of phenomena associated with "triggered" oscillations in motors. The approach of this portion of the program will require application of both approximate and exact solutions to the appropriate governing equations. Verification of the analytical methods will be accomplished by incorporating the methods into motor stability prediction codes and using the codes to predict motor instability behavior. Comparison of code predictions with actual motor behavior will provide indications of the utility of the method(s).

Milestones



Budget

Budget	CFY	CFY+1	CFY+2
Salary	32K	47K	55K
Computer Charges	6K	8K	10K
Materials + Shop Charges	7K	10K	10K
TOTAL	45K	65K	75K

Accomplishments

A 35 GHz millimeter wave system has been adapted to the measurement of both steady and dynamic burning rates of solid propellants. The measurement system, which is not restricted with regard to the size and shape of the propellant sample, is used in conjunction with conventional T-Burner hardware. The choice of microwave components operating in the 35 GHz range was dictated primarily by ready availability of the required components. Other frequencies may ultimately prove useful and the applicability of even higher frequencies should be explored in the future, following successful demonstration of the 35 GHz system. One outstanding advantage of using higher microwave frequencies is that the physical size of the system decreases with increase in frequency. From an operational standpoint, a small physical size is more advantageous than larger systems since a compact waveguide system is easier to physically adapt to burner hardware, is less likely to suffer physical damage in the test enviornment, and can be more readily freed of vibration-induced spurious signals. The present 35 GHz system, for example, occupies about 18 inches of length which allows it to be mounted by a cantilever arrangement at the end of the burner. If the components of the present system were chosen for optimum compactness, the system could be shortened to an overall length of less than 12 inches. The components of the microwave system are arranged as shown in Figure 1.

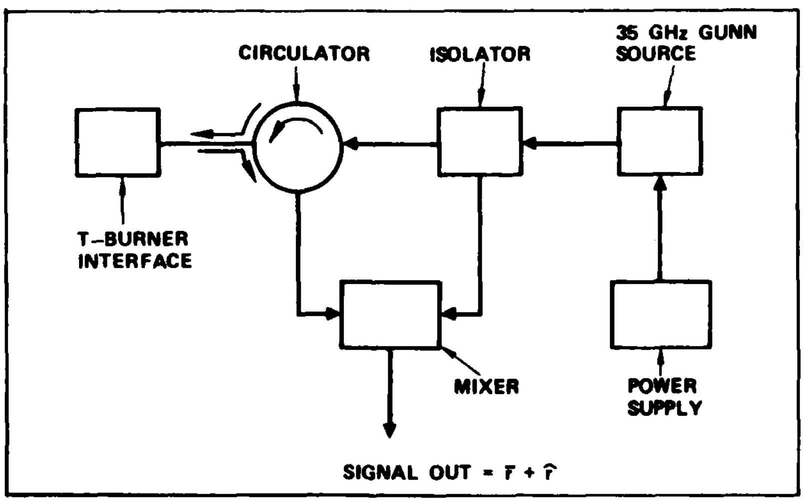


Figure 1. Components of the 35 GHz Microwave System.

A critical factor in the system is the manner by which the millimeter wave energy is transmitted into the propellant sample. A specially designed transition was designed to provide the following features:

1. Provide a mechanical interconnection between the T-burner and the microwave system;

2. Provide a transition from a rectangular waveguide to a circular one (to allow for a circular dielectric transition geometry);

3. Provide for a dielectric transition to allow impedence matching between the waveguide and the propellant;

4. Provide a method for mounting a propellant sample;

5. Provide a method for obtaining an adequate pressure seal between the burner interior and the waveguide system which is safe to operate to several hundred psi; and

6. Provide a convenient method for igniting the propellant sample.

All those requirements were obtained by extensively modifying the basic sample holder design currently used on the NWC T-burner as shown in Figure 2.

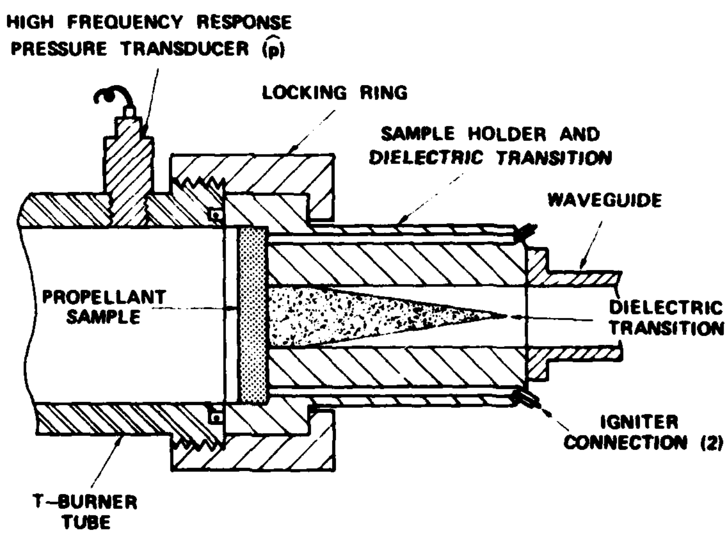


Figure 2. Section of T-Burner/Microwave System Interface.

The microwave system operates in a manner similar to the homodyne doppler radar. The output signal is a voltage that is proportional to the phase difference between the wave imposed on the propellant surface and the wave reflected from the propellant surface in the burner. When a propellant sample burns, the moving surface causes the reflected wave to shift phase with respect to the imposed wave.

The output signal from the microwave system contains all the information needed to obtain the mean burning rate of the sample and the burning rate fluctuations that occur when the propellant sample is subjected to an acoustic pressure perturbation. The mean burn rate signal is determined by the wave length of the microwave signal in the propellant sample and the rate at which the burning surface regresses. Under current operating conditions, the microwave system output voltage appears as a 5 Hz signal. On the other hand, the burn rate fluctuations occur at a rate determined by the frequency of the acoustic pressure which, in the present case, is approximately 170 Hz. Thus, the two signals can be separated by electronic filtering. The burn rate perturbation signal amplitude, however, is a small fraction of the total signal level, being on the same order of magnitude as the ratio of the pressure fluctuation to the mean pressure. Since, in current tests, the maximim pressure perturbation is on the order of 0.03 of the mean pressure, the burn rate perturbation signal requires preamplification. Tests to date indicate that filtering and preamplification of the burn rate perturbation signal is required at the test site to reduce interference by extraneous signals that are picked up by the instrument lines. A typical test record showing data obtained from a test on an aluminized propellant appears in Figure 3.

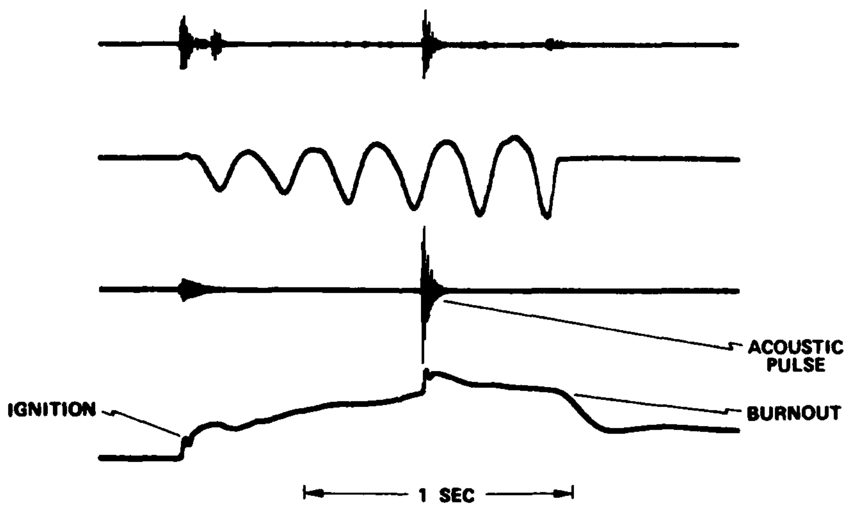


Figure 3. Typical Test Record of Analog Data From the 35 GHz Microwave System.

A series of evaluations is being conducted to determine the validity of the data. That effort is not yet complete but two potential problem areas have been identified and corrected. The first concerns the method by which the propellant sample is mounted in the sample holder. Early testing was done with the propellant grain mounted in a bed of stiff silicone grease. The grease provided adequate inhibiting around the sides of the grain and appeared to position it

satisfactorily in the holder. The advantage of using grease was that with only one transition/sample holder unit available, no time was required for curing of a potting material around the grain. Thus, the use of grease considerably shortened the turnaround time between tests. However, early tests often contained unexplained erratic data and the cause was traced to the grease mounting. The problem was circumvented by returning to a two-component silicone rubber potting material that is normally used in T-burner testing.

The second problem involved use of vibration-sensitive components in the waveguide system which generated signals at the mechanical vibration frequencies of the hardware. The offending components were identified by "rap testing" and were either removed or were replaced by nonsensitive units.

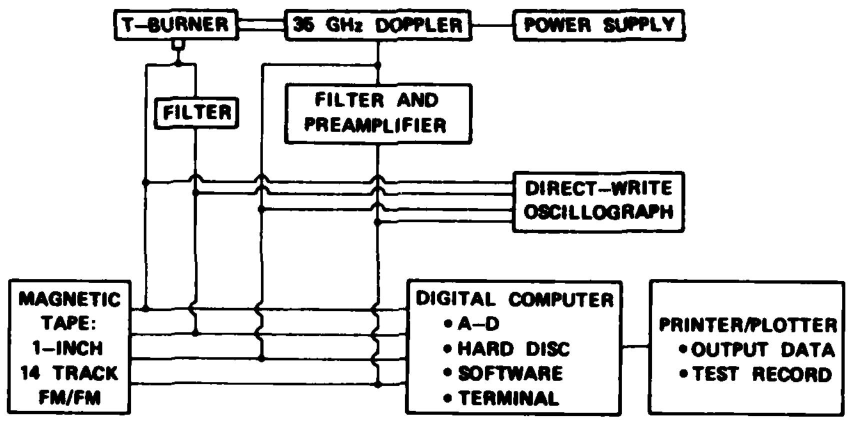
As can be seen in the oscillograph record in Figure 3, acoustic pressure perturbations were generated in the burner by pulsing. That was done as a matter of convenience in the checkout testing. It is intended to explore the feasibility of gathering useful response function data by using pulses, recognizing that there may be time-dependent data processing factors that may limit the conditions under which pulsed data can be successfully used. A relatively simple solution would be to provide for a continuous excitation of the acoustic wave in the manner of a driven burner. That will be accomplished in the present case by the use of an electromagnetic driver at the end of the burner opposite the propellant grain. A driver has been adapted to serve that purpose but evaluation tests with it have not yet been performed.

Data handling and processing is accomplished by a combination of analog and digital techniques as indicated by the block diagram in Figure 4. The magnetic tape, which is currently an analog device, will be used to record data for backup purposes. The oscillograph provides quick-look capability that is considered essential since it enables the test operator to quickly assess major features of a test and he can immediately determine whether further data processing of that test is desirable. The processing of data for determining the acoustic response function will be accomplished with the digital computer. All components of the system are in hand with two exceptions: a high-speed parallel A-D interface is required for the computer and a portion of the computer software which needs to be written. After those elements are in place, additional work will be required to debug the system and to verify the results. A paper describing the microwave measurement system has been prepared and accepted for publication at the 18th JANNAF Combustion Meeting.

Plans

CFY

Major emphasis will be placed on developing laboratory techniques for directly measuring the combustion response of solid propellants to an acoustic environment. Initial effort will be on pressure-coupled response and methods for measuring propellant burning rate by microwave techniques. This effort is interdisciplinary in scope and will require coordination between specialists in



$$R_p = \frac{\hat{r}/\bar{r}}{\hat{p}/\bar{p}} = \text{RESPONSE FUNCTION}$$

Figure 4. Diagram of the 35 GHz Measurement Instrumentation System.

combustion instability, microwave electronics, and in analog and digital signal processing. Experience gained with the pressure-coupled portion of the project will be applied to exploratory investigations into the use of microwave techniques for achieving direct measurement of velocity-coupled response. The velocity-coupled application will require design and fabrication of suitable combustion apparatus.

Work will be initiated to improve and expand existing combustion stability analysis. Effort on both linear and non-linear aspects of acoustic energy contributions in rocket motors are planned. Major emphasis during the year is expected to be on linear phenomena however.

CFY+1

Final testing and documentation of the effort on direct measurement of pressure-coupled combustion response is expected. Work will continue to perfect a suitable method for directly measuring the velocity-coupled combustion response.

Analytical efforts on linear combustion stability will continue with documentation on the significant advances being completed. An effort to treat selected non-linear acoustic phenomena will be added.

CFY+2

Final testing and documentation of a direct method for measuring velocity coupled combustion response is expected. Major analytical efforts will continue on non-linear stability phenomena with documentation of significant achievements being made where appropriate.

Reference

1. Mathes, H. B., and J. W. Battles, "A 35 Gigahertz System for Measurement of Solid Propellant Acoustic Combustion Response." Presented at the *18th JANNAF Combustion Meeting*, 19-23 October 1981. (To be published in proceedings of the meeting.)

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